

Executive Summary

This report presents the results of the remedial investigation (RI) for the Portland Harbor Superfund site. In December 2000, the U.S. Environmental Protection Agency (EPA) identified the Portland Harbor area of the lower Willamette River as a Superfund site and placed it on the National Priorities List. The RI was conducted by the Lower Willamette Group (LWG) pursuant to an Administrative Settlement Agreement and Order on Consent (AOC) with EPA to conduct the remedial investigation and feasibility study. EPA is the lead agency for investigating and selecting a remedy for the in-river portion of the Site, with support from the Oregon Department of Environmental Quality (DEQ). EPA has entered into a Memorandum of Understanding (MOU) with DEQ, six federally recognized tribes, two other federal agencies, and one other state agency,¹ who have all participated in providing support in the development of this document. The RI describes physical conditions of the site, characterizes sources of contaminants, the nature and extent of contamination and processes that affect their movement and fate, evaluates contaminant concentrations in upstream sediment, and assesses potential exposures to contaminants in Portland Harbor sediments and risks to humans and ecological receptors.

STUDY AREA

The Study Area is located in an urban and industrial reach of the lower Willamette River. What was once a shallow, meandering portion of the Willamette River has been redirected and channelized via filling and dredging. A federally maintained navigation channel, extending nearly bank-to-bank in some areas, doubles the natural depth of the river and allows transit of large ships into the active harbor. Much of the riverbank contains overwater piers and berths, port terminals and slips, and other engineered features (armoring such as rip rap makes up approximately half of the harbor shoreline). These extensive physical alterations have resulted in a river reach that bears little resemblance to its pre-industrialized character in terms of hydrodynamics, sediment processes, ecological habitat, and human uses.

The Initial Study Area as defined in the AOC extended from river mile (RM) 3.5 to RM 9.2. Ultimately, the area was expanded upstream and downstream over the course of the RI as additional site characterization data and upland source information were compiled and evaluated, and final Study Area for the RI is a 10-mile stretch of the lower Willamette River. It is located north of downtown Portland between Sauvie Island at RM 1.9 and the Broadway Bridge at RM 11.8. The RI also includes data and source information from areas downstream and upstream of the final RI Study Area,

¹ Government parties that signed the MOU include: the Confederated Tribes and Bands of the Yakama Nation, the Confederated Tribes of the Grand Ronde Community of Oregon, the Confederated Tribes of Siletz Indians, the Confederated Tribes of the Umatilla Indian Reservation, the Confederated Tribes of the Warm Springs Reservation of Oregon, the Nez Perce Tribe, the National Oceanic and Atmospheric Administration, the U.S. Department of the Interior, and the Oregon Department of Fish and Wildlife.

including immediately upstream in the downtown Portland reach (RM 11.9 to 15.3), and an upriver or background reach from RM 15.3 to 28.4.

Today, the Willamette River is noticeably different from the river prior to industrial development that commenced in the mid to late 18th century. Historically, the Willamette River was wider with more sand bars and shoals and flow volumes were subject to greater fluctuation. The main river now has been redirected and channelized, several lakes and wetlands in the lower floodplain have been filled and agricultural lands converted to urban or industrial areas. The end result is a river that is deeper and narrower than it was historically with higher banks that prevent the river from expanding during high-flow events. The Willamette River channel, from the Broadway Bridge (RM 11.6) to the mouth (RM 0), currently varies in width from 600 to 1,900 feet. Further, the installation of a series of dams moderate fluctuations of flow in the lower Willamette River.

Little, if any, original shoreline or river bottom exists that has not been modified by the above actions, or as a result of them. Much of the shoreline has been raised, filled, stabilized, and/or engineered and contains overwater piers and berths, port terminals and slips, stormwater and industrial wastewater outfalls and combined sewer overflows (CSOs), and other engineered features. Constructed structures, such as wharfs, piers, floating docks, and pilings, are especially common in Portland Harbor where urbanization and industrialization are most prevalent. These structures are built largely to accommodate or support shipping traffic within the river and to stabilize the riverbanks for urban development.

Armoring to stabilize banks covers approximately half of the harbor shoreline, which is integral to the operation of activities that characterize Portland Harbor. Riprap is the most common bank-stabilization measure. However, upland bulkheads and rubble piles are also used to stabilize the banks. Seawalls are used to control periodic flooding as most of the original wetlands bordering the Willamette in the Portland Harbor area have been filled. Some riverbank areas and adjacent parcels have been abandoned and allowed to revegetate, and beaches have formed along some modified shorelines due to relatively natural processes.

HUMAN USE

Industrial and urban development of Portland Harbor and adjacent areas has been extensive. The majority of the shoreline in the Study Area is currently zoned for industrial land use and is designated by the City of Portland as an “Industrial Sanctuary,” with associated industrial and commercial worker activities. Portland Harbor also provides recreational opportunities both on the river and along the riverbanks. Additionally, there are residential areas located near the river and upstream and downstream of the Study Area. Recreational activities are associated with the public access areas, such as beaches and boat ramps, and may include water skiing, occasional swimming, and waterfront recreation. Fishing for salmon, sturgeon, and

other species is conducted throughout the Study Area, both by boaters and from locations along the banks. The lower Willamette River also provides Native American ceremonial and subsistence fisheries for Pacific lamprey (particularly at Willamette Falls) and spring Chinook salmon. In addition, transients have been observed camping at various locations within the Study Area.

ECOSYSTEM

Portland Harbor provides habitat for invertebrates, fishes, birds, mammals, amphibians, reptiles, and aquatic plants. Each group makes a contribution to the ecological function of the river, with its relative importance depending on its niche, its abundance, and its interaction with the physical environment. The invertebrate community living in the sediments provide important food for fish and other species in the Study Area. The fish species found in the harbor include numerous species of resident fish, the river also serves as an important pathway for migration of anadromous species such as salmon, lamprey, and sturgeon. The lower Willamette River has been designated by NMFS as critical habitat for several salmon species that migrate through the Study Area. Fish in the harbor provide an important food resource for birds, such as osprey and bald eagle, and some larger fish species like northern pikeminnow and smallmouth bass, and aquatic mammals.

Birds that use the harbor include migratory and resident species. Resident birds such as bald eagle, Canada goose, mallard, spotted sandpiper, great blue heron, other species are also found in the Study Area. Mammals with habitat in the Study Area include beaver, muskrat, raccoon, river otters, and California sea lion. Portland Harbor provides limited habitat for amphibians and reptiles, and most of the native amphibians prefer undisturbed areas that offer seasonal wetlands with emergent plants and shallow waters. Most local reptile species prefer wet vegetated upland habitats.

Aquatic plant communities are used by wildlife for refuge and for nesting and breeding habitat, and they also provide food for herbivores and play a role in the cycling of nutrients. Habitat constraints in Portland Harbor, including muddy water and overwater obstructions that prevent the sun from reaching the bottom plus extensive bank armoring, limit the development of dense submerged and emergent plant communities in the Study Area.

DATA COLLECTED FOR THE REMEDIAL INVESTIGATION

The study area investigation for the Portland Harbor Superfund Site relies on data available from field investigations conducted by the Lower Willamette Group (LWG), with oversight by EPA, as well as data from other sources. These investigations provide information on surface features, contaminant sources, meteorology, media-specific (groundwater, surface water, fish and shellfish tissue, and sediment) chemistry, geology, hydrology (surface water and groundwater), and ecology of the study area.

The Portland Harbor Remedial Investigation (RI) was designed as a multi-year program involving multiple rounds of data gathering and data evaluation as chemical distributions and the factors driving risks to ecological receptors and human health are identified. Site data were collected by the LWG during four major rounds of field investigations between 2001 and 2008, often timed around varying river stages, river flows, and storm events. The field investigations first began in 2001 in the Initial Study Area (ISA) as defined by the AOC, SOW, and Programmatic Work Plan. Studies also included areas downriver of the study area to the confluence with the Columbia River and upriver to RM 28.4. Each sampling event was conducted under an EPA-approved Field Sampling Plan (FSP) and Quality Assurance Project Plan (QAPP) and Health and Safety Plan (HSP). Analytical results were documented in a Field Sampling Report (FSR), data report, and/or Site Characterization Study Report (SCSR).

In 2001 and 2002 the LWG conducted a number of studies as an initial phase of the Portland Harbor RI. These studies were necessary to scope the work plan for conducting the RI. Round 2 sampling began with multiple field efforts in 2004 and focused on the characterization of surface and subsurface sediment quality. In 2006, specialized sampling to support the hydrodynamic sediment transport model (surface sediment erosion rates) was conducted. Round 3 sampling between 2006 and early 2008 included collecting samples of surface water, biota, sediment upstream and downstream of the Study Area, suspended sediments (in-river sediment traps), and stormwater from selected outfalls. Round 3 sampling also filled data gaps related to site characterization, ecological and human health risks, and upriver background.

In addition to the LWG field investigations, the LWG has also reviewed numerous documents that provided information regarding Portland Harbor and the lower Willamette River in order to develop the Conceptual Site Model and guide the sampling programs for this investigation. Physical, chemical and biological data from other parties were obtained primarily from individual LWG members, EPA, Oregon DEQ, the U.S. Geological Survey (USGS), and the U.S. Army Corps of Engineers (USACE).

The sediment, water, and tissue samples discussed above were analyzed for an extensive list of environmental contaminants, including metals, tributyltin ion (TBT), polychlorinated biphenyls (PCBs), dioxins, DDT and other pesticides, semivolatile and volatile organic compounds (SVOCs, VOCs), herbicides, phenols, and polybrominated diphenyl ethers (PBDEs). However, not every sample was analyzed for all these contaminants.

REMEDIAL INVESTIGATION RESULTS

Physical System

Physical characteristics of the site include meteorology, regional geology and hydrogeology, surface water hydrology, the physical system (which includes

bathymetry, sediment characteristics, and hydrodynamics and sediment transport), habitat, and surface features.

The Study Area is located along the southwestern edge of a large geologic structure known as the Portland Basin, which is a bowl-like structure 40 miles long and 20 miles wide, bounded by folded and faulted uplands. The Tualatin Mountains (Portland West Hills) form a ridge that runs parallel to the Willamette River to the west from the Multnomah Channel to the City of Portland. The mountains define the western edge of the Portland Basin, groundwater and creeks and channels along the east face of the mountains flow downward to the Willamette River.

Precipitation falls primarily as rain, with nearly 90 percent occurring between mid-October and mid-May. Rainfall is an important component of source control as it defines storm water and groundwater contaminant migration to the Study Area. It also has a significant effect on the hydrology of the river.

The Willamette River is the 19th largest river in the contiguous United States in terms of discharge, with substantial flows, averaging 33,000 cubic feet per second. Flows vary considerably by season, with the lowest flows occurring during the late-summer dry season, and typically increasing by a factor of 10 through the winter rainy season. River flows in the lower Willamette are regulated to some degree by a series of upstream dams, although high-flow events of 200,000 cubic feet per second or more still occur every few years during large storms. Although Portland Harbor is more than 100 miles from the Pacific Ocean, it is subject to tidal influence, causing the river to rise and fall up to several feet through a tidal cycle. During the dry season, when river discharge is low, rising tides can cause intermittent flow reversals throughout the harbor.

Generally, groundwater flow adjacent to the Study Area is toward the river. On the west side of the river, groundwater and creeks and channels along the east face of the Tualatin Mountains flow downward to the Willamette River. On the east side of the river, starting upstream of RM 4, a broad terrace divides the floodplains of the Willamette and Columbia Rivers. Deep groundwater flows are influenced by the Columbia on the east side of the river, with effects increasing as distance from the Willamette River increases. Groundwater gradients are relatively flat in some areas along the east side of the river, due to both underlying geology and the influence of the Columbia River. The groundwater flow regimes bordering the river show seasonal patterns related to seasonal river stage and precipitation variations. In the absence of preferential pathways, groundwater flow to the sediments and river will tend to be heavily influenced by the location and geometry of higher and lower permeability layers in relation to the river.

The primary factors controlling river flow dynamics, sediment deposition and erosion, and riverbed character appear to be the river cross-sectional area and navigation channel width. The upstream boundary of the Study Area to Willamette Falls is markedly narrower, more confined by bedrock outcrops, and faster flowing than the Portland Harbor reach. The river widens as it enters the Study area and becomes increasing

depositional, most notably in the western portion of the river, until RM 7. From approximately RM 5 to RM 7, the river and navigation channel narrows, and this reach is dominated by higher energy environments with little deposition. From RM 5 to approximately RM 2 the river widens again and becomes depositional, particularly in the eastern portion of the river. Immediately downstream of the Study Area, the river narrows as it turns and converges with the Columbia River. Multnomah Channel exits at RM 3, considerably reducing direct discharge to the Columbia River.

Sediments in some locations may be resuspended and transported downstream during periods of high flow and from anthropogenic disturbances, such as vessel operations in the harbor. The degree of deposition and movement of sediments is controlled largely by river hydrodynamics and the sediment texture (grain size and organic matter content). Suspended fine-grained sediments (silts and clays) are typically transported farther than larger sandy sediments under all flow conditions.

Bathymetric changes from 2002 to 2009 show the greatest net sediment accumulation occurs where the channel is wide and where flow velocities are reduced, these shoals are predominantly fine-grained sediments. Some areas of natural scour and dredging are also evident. Sediments in the scour areas are predominately sand and appear to be relatively stable during low-flow conditions, but are mobilized when flow velocities are high.

Nearshore and off-channel areas, such as Swan Island Lagoon, Willamette Cove, and port terminals, also exhibit deposition. In other areas, such as RM 9-11E, areas within Swan Island Lagoon and Willamette Cove, RM 6-7W, and RM 5-7E, little elevation change and/or small-scale scour was observed. Sediment scour in some nearshore locations appears to be due to ship traffic (wakes and prop wash) and other human activities. These activities also appear to mix surface and subsurface sediments.

Sources of Contamination

Historical releases of contaminants contributed to the majority of the observed chemical distribution in sediments within the Study Area. Contaminants from upland areas have entered the river system as direct discharges through storm water and waste water outfalls, from overwater releases and spills, and indirectly through overland flow, bank erosion, groundwater, and other nonpoint sources. In addition, contaminants from regional sources have reached the Study Area through inputs of surface water and sediment from upstream and through atmospheric deposition. Historical and current sources responsible for the existing contamination include, but are not limited to ship building, repair, and dismantling; wood treatment and lumber milling; storage of bulk fuels and manufactured gas production; chemical manufacturing and storage; municipal combined sewer overflows; and stormwater from industrial, commercial, transportation, residential, and agricultural land uses.

Ongoing sources of contaminants to the Study Area include soil, storm water, groundwater, and river banks. Contaminants also reach the river via direct discharge

through conveyance systems, atmospheric deposition, and overwater activities. Ustream sources within the broader Willamette River Basin contribute to contamination in sediment, surface water, and biota in the Study Area.

Distribution of Contaminants

A subset of contaminants was selected as indicator contaminants in the RI report to facilitate the presentation of the distribution of contamination identified in the Study Area. The indicator contaminants are:

- Total PCBs
- Total polychlorinated dibenzo-*p*-dioxin/furans (PCDD/Fs)
- Total DDx (sum of 2,4'- and 4,4'- dichlorodiphenyltrichloroethane [DDT], -dichlorodiphenyldichloroethane [DDD] and -dichlorodiphenyldichloroethene [DDE])
- Total PAHs
- Bis(2-ethylhexyl)phthalate (BEHP)
- Total chlordanes
- Aldrin
- Dieldrin
- Arsenic
- Chromium
- Copper
- Zinc
- TBT

Sediment

The highest concentrations of contaminants in sediments were typically found in nearshore and off-channel areas such as slips, embayments, and shallow areas, and near some known or suspected sources.

On a site-wide basis, the highest PCB sediment concentrations occur in nearshore areas and in locations proximal to local upland sources. Relatively high concentrations of PCBs are also often found in riparian sediments, sediment trap samples, surface waters, and biota samples in the areas with elevated sediment concentrations. The highest concentrations were observed at RM 11.3E, RM 8.8-10W, Swan Island Lagoon, International Slip (RM 3.7-3.8E), RM 2.1E-2.5E, and RM 4.0 to 4.1E. Total PCB concentrations are generally higher in subsurface sediments, pointing to predominantly historical total PCB sources and higher past loads, although exceptions to this trend are noted at RM 11E, Swan Island Lagoon, and Willamette Cove. Relative PCB concentrations in surface water generally align with those areas having the highest concentrations in sediment. Total PCB concentrations in the Study Area sediment trap samples were one-to-five fold greater than upstream concentrations. Measured PCB concentration in biota are typically found in biota samples from areas with high sediment concentrations.

Total PCDD/Fs were detected in sediments at RM 2E-8E, Swan Island Lagoon, RM 11E, RM 6W-10.3W, from RM 4W-6W, and at RM 3.4W. These areas generally coincide with known or likely historical sources at RM 11E, Swan Island Lagoon, Willamette Cove, and between RM 6.5W and 7.5W. Total PCDD/F concentrations in the subsurface are generally greater than in surface sediments, indicative of a primarily historical inputs. Areas of apparent PCDD/F contamination in sediment in other locations in the Study Area not associated with documented sources and pathways that all point sources may not have been identified. There are no strong spatial or temporal gradients evident in concentrations measured in suspended sediments collected in sediment traps. PCDD/Fs were detected in all fish and invertebrate tissue samples collected from the Study Area, the highest concentrations were in samples collected between RM 6.5 and 7.5.

The highest reported DDx concentrations in sediment are located in the western nearshore zone between RMs 6W and 7.5W, and are proximal to known upland sources. Other areas are smaller in extent and are located at RM 8.8W, at the mouth of Swan Island Lagoon, the International Slip, and RM 4.8W (in subsurface sediment only). Concentrations are typically greater in the subsurface than in the surface layer, indicating DDx sources are primarily historical. The highest DDx concentrations observed in surface water, sediment traps, TZW, and biota samples were all from the area of RM 6.8W to RM 7.5W.

PAHs are present at a wide range of concentrations throughout the Study Area in all media, the highest concentrations in sediment occur downstream of RM 7 in nearshore areas proximal to local upland sources offshore of Siltronic, Gasco, Marine Finance, and Foss Brix. Other locations of elevated total PAH concentrations in surface sediments include Mar Com South (RM 5.5–5.6E), Terminal 4 Slip 3 and Wheeler Bay (RM 4.3–4.6E), Slip 1 (RM 4.3E), and the International Slip (RM 3.7–3.8E). Concentrations are generally higher in subsurface sediments, the most notable exception to this pattern is the navigation channel at RM 5 to 6. Other exceptions to the general pattern of higher subsurface total PAH concentrations include Swan Island Lagoon and Multnomah Channel. The composition of different PAHs in sediment trap and high-flow surface water particulate samples were generally similar to that of sediment. Total PAH concentrations in TZW were reported in areas that correspond with elevated areas of sediment concentrations. The highest concentrations reported in biota samples also correspond with areas where the highest PAH concentrations were found in sediment.

The highest BEHP concentrations detected in sediment are located proximal to local upland sources (Maps 5.1 12a–m and Panels 10.2 5A–B), and are observed in Swan Island Lagoon and in the International Slip (RM 3.7–3.8E), and along the riverside of Schnitzer/Calbag site RM 3.8–4.1E, RM 7.6E, RM 9.7W, RM 8.8W, RM 8.3W, RM 7.6W, and offshore of RM 7.1, and RM 10 in the navigation channel. High concentrations were less widespread in subsurface sediment. BEHP concentrations in sediment trap samples generally did not vary widely spatially or temporally. It was detected in laboratory-exposed clams and worms, mussels, and fish, and was not

detected in crayfish, juvenile Chinook, or carp. With the exception of the surface sediment on the east bank near RM 4 and subsurface sediment at the downstream end of Swan Island, elevated BEHP concentrations in biota do not correlate well with elevated concentrations in sediment.

The highest detected chlordane concentrations in sediment are restricted to small, widely scattered nearshore or off-channel areas, proximal to local upland sources at RM 5.8W-9W, and RM 3E, 4E, 5.5E, and 11E. Total chlordanes were detected in a majority of surface water samples. Reported concentrations in sediment trap samples were low, with no strong temporal or spatial patterns. Chlordanes were detected at low concentrations with varying frequency in all fish and invertebrate samples.

Aldrin and dieldrin contamination in sediment is generally co-located and restricted to small, widely scattered nearshore areas. The highest concentrations were detected at RM 6.8 to 7.5W and RM 8.8W. Overall, aldrin concentrations slightly higher in subsurface than surface sediment, while dieldrin concentrations are generally greatest in surface sediment. Both were detected in particulate and dissolved surface water samples, and were infrequently detected in sediment traps.

Relatively high zinc concentrations were observed in the vicinity of Swan Island Lagoon, and at Terminal 4, high concentrations of copper were also observed in Swan Island Lagoon. With the exception of widely scattered nearshore areas where higher concentrations of arsenic, copper and zinc were noted in sediment, concentrations of these metals are generally consistent across the site. The lack of a discernable concentration gradient between surface and subsurface is indicative of both recent and historical inputs of all three metals. Concentrations in surface water were generally consistent across the entire Study Area, sediment collected in traps show little spatial or temporal trends in measured concentrations. The highest reported arsenic concentrations in TZW are located at the west side of the channel at RM 6.2–6.6, and the west bank at RM 7.7. However, there are no corresponding high arsenic concentrations in sediment. The highest copper and zinc concentrations in TZW were measured offshore of the Gasco and Siltronic sites in areas where no elevated surface sediment concentrations were reported. Arsenic, copper and zinc were detected in nearly all fish and invertebrate species and tissues analyzed from within the Study Area.

Areas of relatively high chromium concentrations in surface and subsurface sediments were noted at the head of the International Slip, RM 2E, RM 4E, RM 6E, Swan Island Lagoon, RM 6W, RM 7W, and RM 9W. The distribution of concentrations in surface and subsurface sediments indicate both recent and historical sources. Results from sediment trap samples show a uniform distribution of chromium concentrations, the highest concentrations in TZW were observed between RM 6.2W and 6.5W, offshore of the Gasco and Siltronic properties. It was detected in all fish and invertebrate species and tissues analyzed within the Study Area.

TBT contamination in sediment is primarily located in the vicinity of the Cascade General Shipyard and adjacent to Swan Island Lagoon. Concentrations in subsurface sediments exhibit slightly higher concentrations than surface sediments, suggesting that contributions from historical inputs were greater relative to current inputs. Upstream of RM 7.5, TBT was detected in sediment trap samples only in Swan Island Lagoon.

Upstream areas characterized during the RI for comparison with the Study Area included the downtown reach (RM 11.9 to 15.3), which is immediately above the Study Area, and a reach from upriver of Ross Island to Willamette Falls (RM 15.3 to 28.4). The Willamette River is narrow in these upstream areas, resulting in higher flow velocities and sandier sediments. Excluding some known or suspected source areas and cleanup sites in the downtown reach, sediment contaminant concentrations in the upstream areas are lower than found in the Study Area.

Locations exhibiting higher elevated contaminant concentrations in the Study Area appear to be physically stable over time. However, migration of some contaminants is evident in limited areas consistent with source types and general sediment transport patterns. Sediments immediately downstream of the Study Area in the Willamette River and Multnomah Channel showed some evidence of contaminant migration from the Study Area.

Suspended Sediments

The areas where the highest concentrations of contaminants were detected in sediment trap samples correspond with areas with high concentrations in surface sediments, indicating the effect of erosion and resuspension of bottom sediment, the presence of current sources, or both. Concentrations of indicator contaminants collected from sediment trap samples in the Study Area had higher than samples collected upstream of the Study Area.

Surface Water

Concentrations of contaminants in surface water within the Study Area are generally higher than those measured in upstream samples under all flow conditions. Elevated concentrations were observed in both transect (cross-river composite samples) and single-point surface water samples at various locations throughout the Study Area. The highest contaminant concentrations in surface water within the Site were found near known sources. At the downstream end of the Study Area and Multnomah Channel, concentrations of total PCBs, dioxin/furans, DDX, BEHP, chlordanes, and aldrin in surface water are greater than concentrations entering the Study Area that indicate contamination from Portland Harbor is being transported downstream to the Columbia River.

Transition Zone Water

Currently, 120 sites have been identified with groundwater contamination. Complete or likely complete groundwater pathways have been identified at 11 sites, 51 sites have insufficient data to make a determination, and 58 sites have been identified as not having a complete pathway. As part of the groundwater pathway assessment

investigation conducted for the RI, samples of TZW and pore water in surface and near-surface sediments were collected offshore of nine upland sites in the Study Area. Based on these efforts, a current complete groundwater pathway with influence on TZW and sediment chemistry was confirmed at four sites, groundwater migration was found to have no significant influence at four other sites, and groundwater effects could not be determined at one site.

Fish and Invertebrate Tissue

Contaminants were detected in a majority of fish and invertebrate species collected throughout the Study Area. Contaminant concentrations varied within and between different species, concentrations in fish tissue were generally greater than in invertebrates. Concentrations of bioaccumulative compounds such as PCBs and DDx were often found at greater concentrations in organisms higher on the food chain and correlated with areas of elevated concentration in sediment. On a site-wide scale, biological samples from within the Study Area exhibited greater concentrations of most indicator contaminants than those seen in samples from upriver reaches and above Willamette Falls. Localized areas of elevated concentrations of some indicator contaminants were found in resident species, reflecting high concentrations in nearby surface sediment and biological uptake by species with small home ranges.

BASELINE HUMAN HEALTH RISK ASSESSMENT

The baseline human health risk assessment (BHHRA) evaluated the potential for adverse human health effects from exposure to contaminants within the Study Area. The general objective of the BHHRA was to assess the potential risks to human health from exposure to contaminants present in sediment, surface water, and groundwater seeps, or accumulating in fish and shellfish.

Approach to the Baseline Human Health Risk Assessment

Currently or potentially exposed populations were identified based on consideration of both current and potential future uses of the Study Area, and include populations who may be exposed to contamination through a variety of activities. The specific populations and exposure pathways evaluated were:

- Dockside workers — direct exposure via incidental ingestion and dermal contact with beach sediments.
- In-water workers — direct exposures to in-water sediment.
- Transients — direct exposure to beach sediment, surface water for bathing and drinking water scenarios, and groundwater seeps.
- Recreational beach users — direct exposure to beach sediment and surface water while for swimming.

- Tribal fishers — direct exposure to beach or in-water sediments, and consumption of migratory and resident fish.
- Recreational and subsistence fishers — direct exposure to beach or in-water sediments, consumption of resident fish, and consumption of shellfish.
- Divers — direct exposure to in-water sediment and surface water.
- Domestic water user — direct exposure to untreated surface water potentially used as a drinking water source in the future.
- Infants - consumption of human breast milk.

The presence of uncertainty is inherent in the risk assessment process, and EPA policy calls for numerical risk estimates to always be accompanied by descriptive information regarding the uncertainties of each step in the risk assessment to ensure an objective and balanced characterization of the true risks and hazards. Additionally, it is important to note that the risks presented here are based on numerous conservative assumptions in order to be protective of human health and to ensure that the risks presented are more likely to be overestimated rather than underestimated.

Results of the Baseline Human Health Risk Assessment

The major findings of the BHHRA are:

- Estimated cancer risks resulting from the consumption of fish or shellfish are generally orders of magnitude higher than risk resulting from direct contact with sediment and surface water. Risks and noncancer hazards from fish and shellfish consumption exceed the EPA point of departure for cancer risk of 1×10^{-4} and target hazard index (HI) of 1 when evaluated on a harbor-wide basis, and when evaluated on the smaller spatial scale by river mile. Consumption of resident fish species consistently results in the greatest risk estimates. Evaluated harbor-wide, the estimated RME cancer risks are 4×10^{-3} and 1×10^{-2} for recreational and subsistence fishers, respectively.
- Noncancer hazard estimates for consumption of resident fish species are greater than 1 at all river miles. Based on a harbor-wide evaluation of noncancer risk, the estimated RME HI is 300 and 1,000 for recreational and subsistence fisher, respectively. The highest hazard estimates for recreational fishers are at RM 4, RM 7, RM 11, and in Swan Island Lagoon.

The highest noncancer hazards are associated with nursing infants of mothers who consume resident fish from Portland Harbor. When resident fish consumption is evaluated on a harbor-wide basis, the estimated RME HI is 4,000 and 10,000 for breastfed infants of recreational and subsistence fishers, respectively. Evaluated on a harbor-wide scale, the estimated RME HI for tribal consumers of migratory and resident fish is 600 assuming fillet-only consumption, and 800 assuming whole-body consumption. The corresponding

HI estimates for nursing infants of mothers, who consume fish, are 8,000 and 9,000 respectively, assuming maternal consumption of fillet or whole-body fish.

- PCBs are the primary contributor to risk from fish consumption harbor-wide. When evaluated on a river mile scale, dioxins/furans are a secondary contributor to the overall risk and hazard estimates, particularly at RM 6 and 7. PCBs are the primary contributors to the noncancer hazard to nursing infants, primarily because of the bioaccumulative properties of PCBs and the susceptibility of infants to the developmental effects associated with exposure to PCBs.

ECOLOGICAL RISK ASSESSMENT

The baseline ecological risk assessment (BERA) evaluated the potential for adverse effects on plants, invertebrates, amphibians, fish, and wildlife from contaminants within the Study Area. The primary objective of the BERA was to characterize the risks of chemical effects on these aquatic and aquatic-dependent ecological receptors in the Study Area.

Approach to the Baseline Ecological Risk Assessment

The following complete and significant exposure pathways were quantitatively evaluated in the BERA using multiple lines of evidence:

- **Benthic invertebrates**—Direct contact with sediment and surface water, ingestion of biota and sediment, and direct contact with shallow TZW
- **Fish**—Direct contact with surface water, direct contact with sediment (for benthic fish receptors), ingestion of biota, incidental ingestion of sediment, and direct contact with shallow TZW (for benthic fish receptors)
- **Birds and mammals**—Ingestion of biota and incidental ingestion of sediment
- **Amphibians and aquatic plants**—Direct contact with surface water and shallow TZW.

The assessment endpoints for all ecological receptors are based on the protection and maintenance of their populations and the communities in which they live, with the exception of special status species (species that are protected by federal and/or state regulations or otherwise deemed culturally significant), which are assessed at the organism-level for survival, growth, and reproduction. In Portland Harbor, juvenile Chinook salmon, Pacific lamprey ammocoetes, and bald eagle were identified as special status species. For practical reasons and to be conservative, the organism-level measurement endpoints (survival, growth, and reproduction) were used for all receptors, requiring extrapolation to assess risks to populations and communities.

Results of the Baseline Ecological Risk Assessment

The following presents the primary conclusions of the BERA:

- In total, 93 contaminants (as individual contaminants, sums, or totals) pose potentially unacceptable ecological risk. Grouping individual PCB, DDx, and PAH compounds reduces the number to 66.
- Risks to benthic invertebrates are clustered in 17 benthic areas of concern.
- Sediment and TZW samples with the highest hazard quotients for many contaminants also tend to be clustered in areas with the greatest benthic invertebrate toxicity.
- PAH and DDx compounds are the contaminants of potential concern in sediment that are most commonly spatially associated with locations of potentially unacceptable risk to the benthic community or populations.
- The most ecologically significant contaminants are PCBs, PAHs, dioxins and furans, and DDT and its metabolites. PAHs and DDx risks are largely limited to benthic invertebrates and other sediment-associated receptors. PCBs tend to pose their largest ecological risks to mammals and birds.
- The combined toxicity of dioxins/furans and dioxin-like PCBs, expressed as total TEQ, poses the potential risk of reduced reproductive success in mink, river otter, spotted sandpiper, bald eagle, and osprey.

CONCLUSIONS

The key findings of the RI include the following:

Sources of Contamination

Most of the sediment contamination at the Site is associated with known or suspected historical sources and practices. Ongoing contaminated groundwater plumes, river bank soils, and upstream surface water. The distribution of contaminants in sediments in several nearshore areas appears to reflect more significant historical lateral inputs. The spatial correlation between PCBs in aquatic organisms and sediments indicates that contamination in bottom sediments is an ongoing source of persistent bioaccumulative contaminants such as PCBs, DDx and dioxin/furans contamination to biota.

Nature and Extent of Contamination

- Sediments in Portland Harbor reflect the industrial, marine, commercial, and municipal practices for over 100 years in this active industrial, urban, and trade corridor, as well as agricultural activities in the Willamette Basin.

- Higher concentrations of contaminants in sediments occur in nearshore and off-channel areas that are generally associated with known or likely historical or current sources.
- Contaminant concentrations in sediment are generally higher at depth than in the surface layer, indicating that past contaminant inputs were greater than current inputs, and that surface sediment quality has improved over time. The few exceptions include areas where higher surface sediment concentrations appear to be associated with ongoing local sources, low rates of sediment deposition, and physical sediment disturbance (e.g., from boat scour).

Fate and Transport

The major internal fate and transport processes are:

- Erosion from the sediment bed
- Deposition to the sediment bed
- Dissolved flux from the sediment bed (porewater exchange)
- Groundwater advection
- Degradation (for some contaminants)
- Volatilization
- Downstream transport of either particulate-bound or dissolved phase contaminants

These processes interact to create complex patterns of contaminant redistribution that vary over space, time, and by contaminant. Patterns of contamination in bedded surface sediment suggest some redistribution of contaminants over time. In some areas this is limited by re-burial of much of the source area contamination, as indicated by higher subsurface sediment concentrations in these areas. In other areas, periodic erosion may temporarily expose buried contamination and disburse contaminants downstream.

Groundwater plume advection and release has been observed in several areas along with dissolved phase flux from surface sediments to the water column. Limited sampling of groundwater effects on pore water in the Study Area has been conducted and further sampling will need to be conducted in Remedial Design.

Based on results of surface water data collected during the RI, resuspension and/or dissolved phase flux from the sediment bed are contributing to contaminant concentrations in surface water, particularly in quiescent areas where surface water mixing and dilution is minimal. Loading estimates are consistent with this concept,

indicating the mass flux of contaminants exiting the downstream end of the Study Area in surface water (either directly to the Columbia River or via Multnomah Channel) is greater than the flux entering the Study Area. Contaminant concentrations in loads entering the Study Area from adjacent upland sources and pathways (such as stormwater) are generally greater than concentrations in the upstream loads (upriver surface water and sediments). Stormwater input is the most important current source pathway within the Study Area for many contaminants, including PCBs and DDx.

Finally, empirical tissue contaminant data and food web modeling indicate that persistent contaminants (particularly PCBs and dioxin/furans) in sediments and surface water bioaccumulate in aquatic species tissue. All the data taken together (surface water, sediment, sediment traps), there is evidence that contaminants from the Study Area are migrating downstream to either the Columbia River or Multnomah Channel.

Estimates of Risk

There is unacceptable risk to both human and ecological receptors (cancer risk and noncancer hazard greater than those defined as acceptable by the NCP).

The greatest risk to humans is through consumption of contaminated fish and shellfish. Contaminants that contribute the most risk include:

- Aldrin
- Arsenic
- BEHP
- Chlordanes
- DDx Compounds
- Dieldrin
- Hexachlorobenzene
- Mercury
- Pentachlorophenol
- PBDEs
- PCBs
- Carcinogenic PAHs
- Dioxins and Furans

There are 19 contaminants posing ecologically significant risk:

- PCBs
- Dioxins and Furans

- PAHs
- DDT and metabolites
- Total chlordanes
- Mercury
- Lead
- Cadmium
- Copper
- Zinc
- Dieldrin
- Lindane
- BEHP
- TPH (C₁₀-C₁₂ aliphatic)
- Tributyltin
- Cyanide
- Ethylbenzene
- Perchlorate
- Manganese